Modeling transient gain dynamics in a cladding-pumped Yb-doped fiber amplifier pulsed at low repetition rates

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Abstract: Simulations of 1-50 kHz repetition rate, pulsed Yb- fiber amplifiers show peak powers to 10 kW with half-widths < 30 ns, consistent with commercial amplifier performance. This device is a potential source for deep-space communication.

For space-based optical communication links, high peak-power laser sources with repetition rates less than 100 kHz are required. A potential candidate is the high power, cladding-pumped, Yb-doped fiber amplifier (YDFA) with a pulse-position-modulated seed oscillator. A device developed under contract by IPG Photonics met the requirements of almost 10 kW peak power with pulsewidths less than 30 ns at 3.5 kHz as shown in Fig. 1. However, at higher repetition rates (20 to 50 kHz), nearly flat pulses with peak power less than 1 kW were obtained (Fig. 1). To understand and optimize this behavior, we have simulated the performance of a pulsed YDFA.

Er-doped fiber amplifiers exhibit transient gain dynamics on time scales substantially shorter than the upper state lifetime of Er in glass (10 ms) [1]. Thus it is not surprising that such effects should be observed in YDFAs where the upper state lifetime $\tau_{Yb} \sim 1$ ms [2]. Here we show that conventional solution [1, Appendix S] to the rate and power equations in space and time yields spiking to 10 kW for YDFAs with average powers of 1 to 2 W and PRFs < 10 kHz, as seen in the commercial amplifier.

We solve the differential equations for forward and backward pump, signal, and fractional Yb inversion (see [3] eqs. 5.49 and 5.53 in Er context). We include gain and loss at pump and signal wavelengths (975 and 1060 nm), and linear loss with time constant of $\tau_{Yb} = 0.25$ to 1 ms in the inversion equation. The optical equations are solved in terms of a spatial integral of the inversion and substituted into the inversion rate equation; then this equation is solved with a split-step algorithm. We simulate bidirectionally pumped YDFA, since this seems most likely for the final stage in a multi-stage device, and we expect the final stage to give the largest spiking in power.

We use parameters thought typical of a YDFA, but emphasize that we have no explicit knowledge of the details of the commercial amplifier that stimulated this investigation, nor are we trying to model its specific performance: Yb density = 10^{25} m^{-3}, core radius = 3.3 microns, clad radius = 10 microns, pump-wavelength emission cross section = absorption cross sections = 10^{-24} m^2, signal-wavelength absorption cross section = 0 and emission cross section = 0.15 10^{-24} m^2.

Fig. 1 shows the peak power of the output spike as a function of PRF with Yb lifetime as parameter for a 13-m amplifier bidirectionally pumped by 2 1-Watt cw lasers with input signal of 600-mW. Note that the results for $\tau_{Yb} \sim$ 0.5 ms are consistent with the data. Calculations show that the spike power is very sensitive to amplifier properties; Fig. 2 shows spike power versus fiber length while Fig. 3 shows spike power versus pump power. In each example the spiking turns on abruptly.

Further calculations include ASE, a cw secondary wavelength or polarization input signal, a rounded leading edge, a multistage amplifier, and forward or backward pumping.

Fig. 1. Peak power as a function of repetition rate (PRF) calculated for $\tau_{Yb} = 0.25$ (solid), 0.5 (dotted), 1 ms (dashed) and measured (points). The insert shows the pulse shapes measured at 3.5, 20 and 50 kHz (top to bottom).

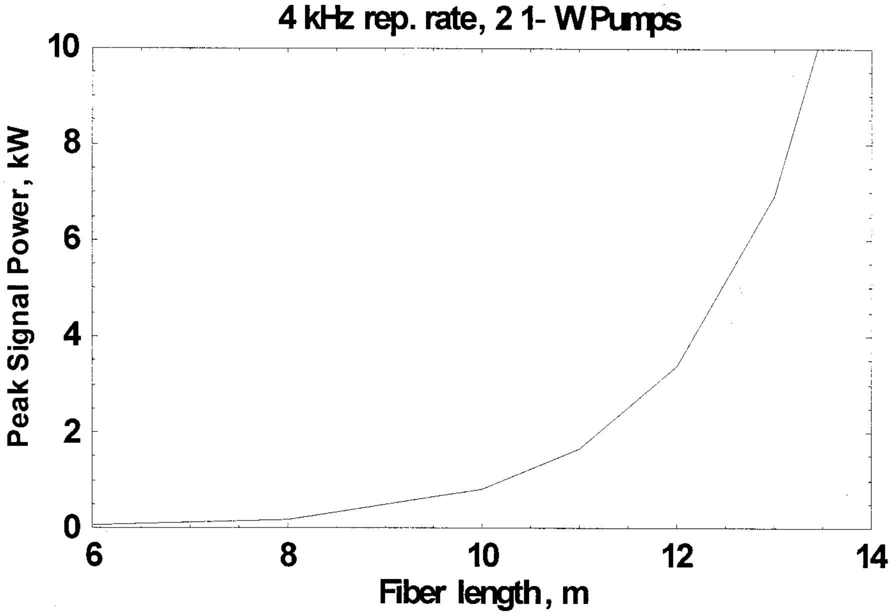

Fig. 2 Peak amplified signal power as a function of fiber length.

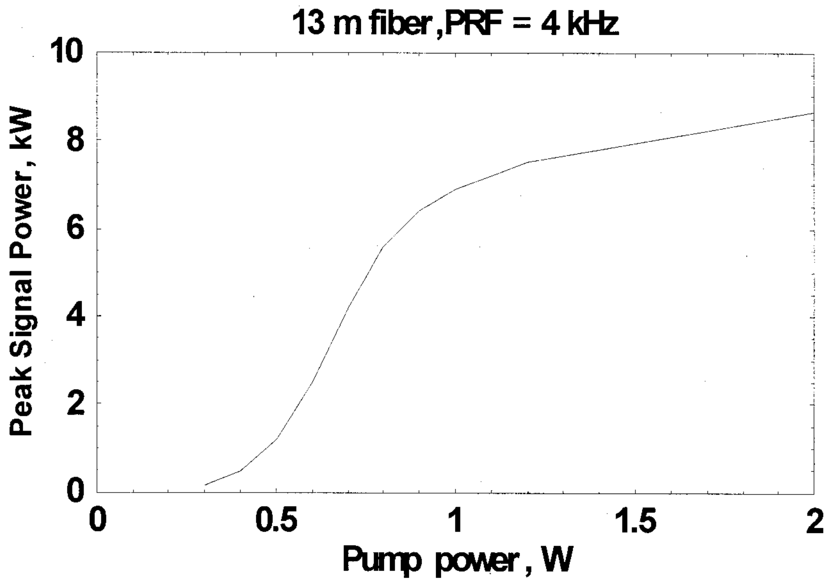

Fig. 3 Peak amplfied signal power as a function of pump power.

References
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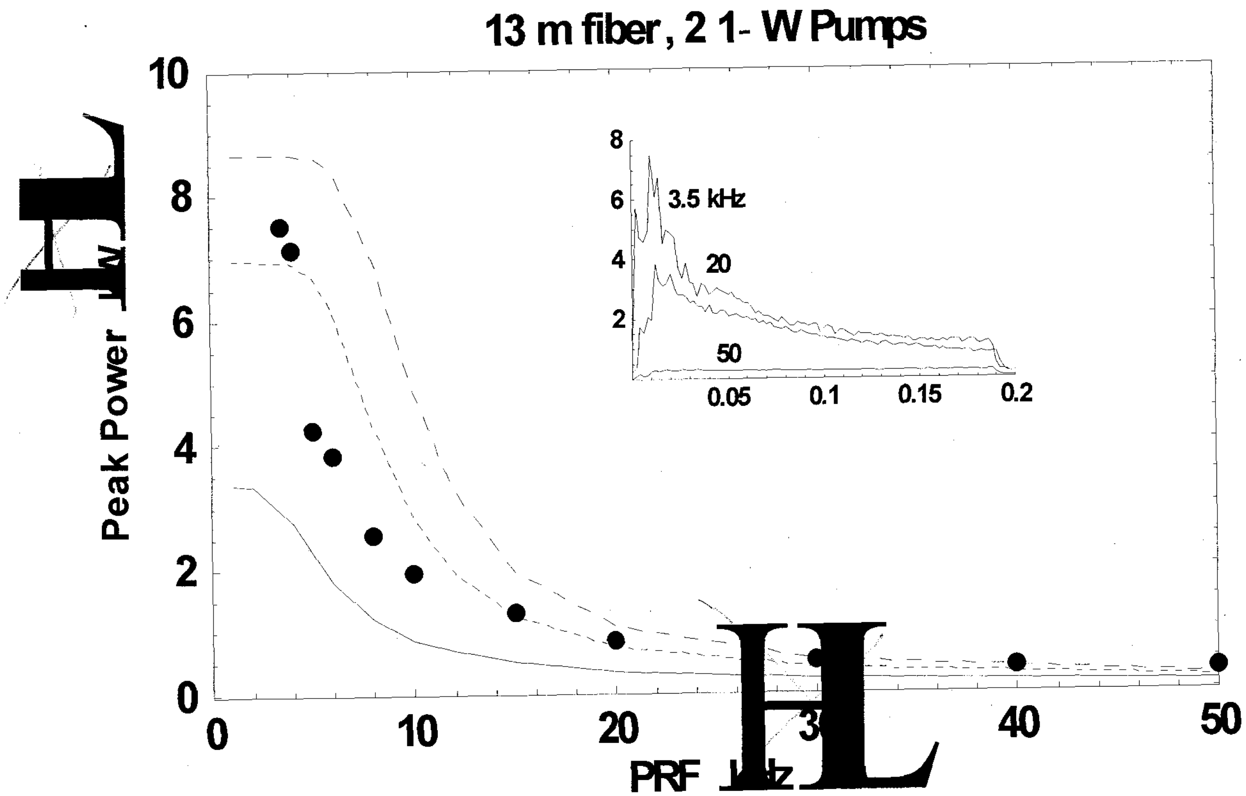

Fig 1